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DESCRIPTION

PHASE ERROR CORRECTION CIRCUIT

TECHNICAL FIELD

[0001] The present invention relates to a demodulator for demodulating a VSB (vestigial-sideband) modulated signal, and more particularly relates to a phase error correction circuit.

BACKGROUND ART

[0002] FIG. **4** is a block diagram illustrating a configuration of a known phase error correction circuit (for example, see Patent Reference 1). The circuit of FIG. **4** includes a waveform equalizer **82**, a complex phase rotator **84** and a specific frequency component elimination filter **86**.

[0003] The waveform equalizer **82** corrects a waveform distortion of a VSB signal **VS** which is a baseband signal and has been analog-digital converted, and outputs the VSB signal to the complex phase rotator **84**. The complex phase rotator **84** multiplies, in terms of a complex signal representation, an output of the waveform equalizer **82** by a complex conjugate signal **CP1** of a detected phase error. Thus, the output signal of the waveform equalizer **82** is reversely rotated by an amount corresponding to the phase error, thereby reconstructing an original VSB baseband signal. The specific frequency component elimination filter **86** eliminates a specific frequency component included in a NTSC (national television system committee) signal and the like from the signal which has been phase corrected and output from the complex phase rotator **84**, and outputs a resultant signal.

[0004] FIG. **5** is a block diagram illustrating another exemplary configuration of a known phase error correction circuit. The circuit of FIG. **5** includes, in addition to components described in FIG. **4**, a Hilbert transformer **92**, a phase error detector **94**, a low pass filter **96** and a complex signal generator **98**.

[0005] The specific frequency component elimination filter **86** eliminates a specific frequency component from the VSB signal **VS** and outputs a resultant signal. The waveform equalizer **82** corrects a waveform distortion of the VSB signal from which the specific frequency component has been eliminated and a resultant real signal to the Hilbert transformer **92**. The Hilbert transformer **92** generates a complex signal from an output of the waveform equalizer **82** and outputs a resultant signal to the complex phase rotator **84**.

[0006] The complex phase rotator **84** multiplies, in terms of complex signal presentation, an output of the Hilbert transformer **92** by a complex conjugate signal **CP2** of a detected phase error and outputs a complex signal **RP2** from which a phase error has been eliminated. The phase error detector **94** detects a phase error of the complex signal **RP2**. The detected phase error is smoothed by the low pass filter **96** and then, based on a resultant smoothed signal, the complex signal generator **98** generates the complex conjugate signal **CP2**.

(Patent Reference 1) Japanese Patent Laid-Open Publication No. 8-242394

DISCLOSURE OF THE INVENTION

PROBLEMS THAT THE INVENTION IS TO SOLVE

[0007] However, in the configuration of FIG. **4**, an output of the waveform equalizer has to be a complex signal. The waveform equalizer normally includes a filter with a large number of taps. To output a complex signal, the number of filters has to be increased, compared to the case where a real signal is output. As a result, a circuit size of the

waveform equalizer is largely increased.

[0008] In the configuration of FIG. 5, an output of the waveform equalizer is a real signal and thus a circuit size can be small. However, a quadrature component of a complex signal is generated by the Hilbert transformer. That is, a complex signal is generated from a real signal having a phase error. If phase correction is performed to such a complex signal, degradation of a frequency component around a DC (direct current) due to an asymmetric frequency characteristic of a VSB signal is caused, so that phase error correction can not be correctly performed. As a result, the degree of degradation of a received signal of a demodulator using the phase error correction circuit of FIG. 5 is increased.

[0009] The present invention has been devised to perform highly precise phase error correction and suppress increase in circuit size of a phase error correction circuit.

SOLUTION TO THE PROBLEMS

[0010] A phase error correction circuit according to the present invention includes: a complex phase rotator for multiplying an input VSB (vestigial-sideband) signal by a phase correction signal and outputting a resultant signal; a specific frequency component elimination filter for eliminating a specific frequency component from the signal output from the complex phase rotator and outputting a resultant signal; a waveform equalizer for performing waveform distortion correction to the signal output from the specific frequency component elimination filter and outputting a resultant signal; and a phase correction signal generator for detecting a phase error based on the signal output from the waveform equalizer and outputting a complex signal corresponding to the detected phase error as the phase correction signal.

[0011] Thus, phase correction is performed to an input VSB signal, so that highly precise phase error correction can be performed.

[0012] Moreover, in the phase error correction circuit, it is preferable that the waveform

equalizer receives a complex signal from the specific frequency component elimination filter and outputs a real signal as the resultant signal obtained from the waveform distortion correction.

[0013] Thus, the waveform equalizer does not have to output a complex signal, so that increase in circuit size of the waveform equalizer can be suppressed.

[0014] It is preferable that the phase correction signal generator includes a Hilbert transformer for performing Hilbert transform to the signal output from the waveform equalizer and outputting a complex signal obtained from the Hilbert transform and detects the phase error based on the Hilbert-transformed complex signal.

[0015] Thus, even though the waveform equalizer does not output a complex signal, a phase difference can be obtained based on a complex signal.

[0016] It is preferable that the phase correction signal generator further includes: a phase error detector for detecting the phase error based on the Hilbert-transformed complex signal and outputting the detected phase error; a low pass filter for smoothing the detected phase error output from the phase error detector and outputting the smoothed signal; and a complex signal generator for generating a complex signal corresponding to the signal output from the low pass filter and outputting the generated complex signal as the phase correction signal.

[0017] It is preferable that the phase error detector includes: a slicer for estimating an original signal symbol value of the VSB signal from an in-phase component of an input complex signal; a subtracter for obtaining a difference between an in-phase component of the Hilbert-transformed complex signal and the estimated signal symbol value output from the slicer; and an integrator for obtaining a product of the difference output from the subtracter and a quadrature component of the Hilbert-transformed complex signal and outputting a resultant product as the phase error.

[0018] It is preferable that the phase error correction circuit further includes a small phase error corrector for detecting a phase error based on the Hilbert-transformed complex signal, performing correction of the phase error of the Hilbert-transformed complex signal according to the detected phase error, and outputting a phase-corrected signal.

[0019] Thus, phase error correction is further performed to a phase-error-corrected complex signal after Hilbert transform, so that more precise phase error correction can be performed.

[0020] It is preferable that the small phase error corrector includes: a small complex phase rotator for multiplying the Hilbert-transformed complex signal by a small phase error correction signal and outputting a resultant signal; a phase error detector for detecting the phase error based on the signal output from the small complex phase rotator and outputting the detected phase error, a low pass filter for smoothing the detected phase error output from the phase error detector and outputting the smoothed signal; and a complex signal generator for generating a complex signal corresponding to the signal output from the low pass filter and outputting the generated complex signal as the small phase error correction signal.

[0021] Thus, a circuit causing a large delay does not exist in the small phase error corrector. Accordingly, while a small phase error can be tracked, a phase error can be corrected.

[0022] It is preferable that the specific frequency component elimination filter has a narrow band elimination filter for eliminating a specific frequency component.

[0023] It is preferable that the narrow band elimination filter eliminates a component of a carrier frequency in a NTSC signal.

[0024] It is preferable that the narrow band elimination filter eliminates a direct current component.

[0025] It is preferable that the specific frequency component filter has a narrow band elimination filter of which an elimination frequency band is variable.

EFFECTS OF THE INVENTION

[0026] In a phase error correction circuit according to the present invention, highly precise phase error correction can be performed. Therefore, degradation of a signal received by a demodulator using the phase error correction circuit can be suppressed. A waveform equalizer outputs not a complex signal but a real signal, so that increase in circuit size can be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] [FIG. **1**] FIG. **1** is a block diagram of a phase error correction circuit according to a first embodiment of the present invention.

[FIG. **2**] FIG. **2** is a block diagram illustrating a configuration of a phase error detector of FIG. **1**.

[FIG. **3**] FIG. **3** is a block diagram of a phase error correction circuit according to a second embodiment of the present invention.

[FIG. **4**] FIG. **4** is a block diagram illustrating a configuration of a known phase error correction circuit.

[FIG. **5**] FIG. **5** is a block diagram illustrating another configuration of the known phase error correction.

EXPLANATION OF REFERENCE NUMERALS

[0028]

12, 52	Complex phase rotator
14	Specific frequency component elimination filter
16	Waveform equalizer

20, 40	Phase correction signal generator
22	Hilbert transformer
24, 54	Phase error detector
26, 56	Low pass filter
28, 58	Complex signal generator
32	Slicer
34	Subtracter
36	Integrator
50	Small phase error corrector

BEST MODE FOR CARRYING OUT THE INVENTION

[0029] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings.

[0030] (First Embodiment)

FIG. **1** is a block diagram illustrating a phase error correction circuit according to a first embodiment of the present invention. The phase error correction circuit of FIG. **1** includes a complex phase rotator **12**, a specific frequency component elimination filter **14**, a waveform equalizer **16** and a phase correction signal generator **20**. The phase correction signal generator **20** includes a Hilbert transformer **22**, a phase error detector **24**, a low pass filter **26** and a complex signal generator **28**.

[0031] An A/D converted VSB signal **VS** and a phase correction signal **CS** which is a complex signal for correcting a phase error are input to the complex phase rotator **12**. The VSB signal **VS** is a baseband signal. The complex phase rotator **12** rotates a phase of the VSB signal **VS** by multiplying the VSB signal **VS** by the phase correction signal **CS** to correct a phase error of the VSB signal **VS** so that the phase error of the VSB signal **VS** is

reduced. The complex phase rotator **12** outputs the phase-error-corrected VSB signal to the specific frequency component elimination filter **14**.

[0032] The specific frequency component filter **14** includes, for example, one or more narrow band elimination filters. A narrow band elimination filter eliminates a frequency component of a frequency specific to the narrow band elimination filter and frequency components around the specific frequency. A notch filter is an example of narrow band elimination filters. The specific frequency component elimination filter **14** eliminates a specific frequency component from the phase-error-corrected VSB signal and outputs a resultant signal to the waveform equalizer **16**.

[0033] For example, assume that the specific frequency component elimination filter **14** is configured to eliminate components of carrier frequencies in a NTCS (national television system committee) signal, i.e., a video carrier frequency, a color subcarrier frequency and a sound carrier frequency, and components around the carrier frequencies. Thus, influences of a NTSC signal on the same channel as a received VSB signal can be suppressed. Moreover, the specific frequency component elimination filter **14** is configured so as to eliminate a DC component. The specific frequency component elimination filter **14** may be configured so as to eliminate some other frequency component which has not described herein or may include a narrow band elimination filter for eliminating components in a variable frequency band.

[0034] The waveform equalizer **16** performs correction of a waveform distortion generated due to intersymbol interference and the like to the VSB signal which is a complex signal, from which a specific frequency component has been eliminated and outputs a resultant real signal, i.e., a waveform-distortion-corrected signal **RS**. The phase correction signal generator **20** extracts phase error information from the waveform-distortion-corrected signal **RS**, obtains a complex signal corresponding to the phase error

information and outputs the complex signal as a phase correction signal **CS** to the complex phase rotator **12**.

[0035] The phase correction signal generator **20** will be described. The Hilbert transformer **22** performs Hilbert transform to the waveform-distortion-corrected signal **RS** and outputs a complex signal **HB** obtained through Hilbert transform to the phase error detector **24**. The phase error detector **24** detects a phase error from the complex signal **HB** and outputs a result of the detection as phase error information **PE** to the low pass filter **26**.

[0036] The low pass filter **26** smoothes the phase error information **PE** and outputs the smoothed phase error information **PE** to the complex signal generator **28**. The complex signal generator **28** generates, based on an output of the low pass filter **26**, the phase correction signal **CS** for correcting a phase error of the VSB signal **VS** and outputs the generated phase correction signal **CS** to the complex phase rotator **12**. The phase correction signal **CS** is a complex conjugate signal of the detected phase error.

[0037] Now, details of phase error detection will be discussed. Assume that symbol information mapped in a transmitter exists in each of in-phase component and quadrature component of the complex signal **HB**. When an input complex signal **HB** is $I + jQ$ and an original complex signal is $D_i + jD_q$, a phase error P_{err} between the signals can be expressed by the following equations:

$$P_{err} = I * (D_i - I) - Q * (D_q - Q) + j\,(Q * (D_i - I) - I * (D_q - Q))$$

[0038] When respective symbol errors of an in-phase component I and a quadrature component Q of the complex signal **HB** are $S_i = (D_i - I)$ and $S_q = (D_q - Q)$, the following equation holds:

$$P_{err} = I * S_i - Q * S_q + j\,(Q * S_i - I * S_q)$$

When a phase error is approximated by a size of the quadrature component, the following equation holds:

$$P_{err} \approx Q * S_i - I * S_q$$

Then, since a symbol error of the quadrature component does not exist in the VSB signal, the following equation holds:

$$P_{err} = Q * S_i$$

[0039] Then, the phase error detector **24** calculates a difference between the in-phase component I of the complex signal **HB** and the original signal symbol value D_i of the VSB signal estimated from the in-phase component and detects as the phase error P_{err} a result from multiplication of an obtained value for the difference and the quadrature component Q.

[0040] FIG. **2** is a block diagram illustrating a configuration of the phase error detector **24** of FIG. **1**. The phase error detector **24** of FIG. **2** includes a slicer **32**, a subtracter **34** and an integrator **36**. The slicer **32** estimates the original signal symbol value D_i of the VSB signal from the in-phase component of the Hilbert-transformed complex signal **HB** and outputs the original signal symbol value D_i to the subtracter **34**.

[0041] The subtracter **34** obtains a difference S_i between the symbol value D_i and the in-phase component I of the complex signal **HB** and outputs the obtained difference S_i to the integrator **36**. The integrator **36** multiplies the difference S_i and the quadrature component Q of the complex signal **HB** and outputs a result of the multiplication as the phase error information **PE**.

[0042] As described above, in the phase error correction circuit of FIG. **1**, a VSB signal which has been phase-error-corrected and is output from the complex phase rotator **12** is a signal from which a frequency error, i.e., an integral of a phase error has been eliminated. Therefore, the specific frequency component elimination filter **14** can eliminate a specific frequency component to be eliminated at high accuracy.

[0043] Also, even though only a real signal is output from the waveform equalizer **16**, a

phase of the VSB signal **VS** is rotated by multiplying the input VSB signal **VS** by the phase correction signal **CS**. Thus, highly precise phase error correction can be achieved. Therefore, degradation of a signal received by a demodulator using the phase error correction circuit can be suppressed.

[0044] (Second Embodiment)

FIG. **3** is a block diagram illustrating a phase error correction circuit according to a second embodiment of the present invention. The phase error correction circuit of FIG. **3** includes a complex phase rotator **12**, a specific frequency component elimination filter **14**, a waveform equalizer **16**, a phase correction signal generator **40** and a small phase error corrector **50**. The phase correction signal generator **40** includes the same components as those of the phase correction signal generator **20** of FIG. **1**. The small phase error corrector **50** includes a complex phase rotator **52**, a phase error detector **54**, a low pass filter **56** and a complex signal generator **58**. Each member also described in the first embodiment is identified by the same reference numeral, and therefore the description thereof will be omitted.

[0045] The phase error correction circuit of FIG. **1** includes in its loop a waveform equalizer having a large number of taps. Thus, in the phase error correction circuit, a large loop delay is caused and a response performance of the phase error correction circuit with respect to a small phase change is not great. To reduce small phase change, the small phase error corrector **50** corrects a complex signal **HB** generated in the phase correction signal generator **40** and outputs the corrected complex signal **HB**.

[0046] A quadrature component of the complex signal **HB** is generated from the waveform-distortion-corrected signal **RS** which is a real signal by Hilbert transform. That is, when a small phase error change is caused, a complex signal is generated from a real signal including the small phase error change. In this case, an error in a frequency

component around a DC is increased due to a frequency characteristic of a VSB signal. However, such an error does not occur when a phase error is 0 degree and a maximum error occurs when a phase error is 90 degrees. Generation of a complex signal from a real signal has very small influence on detection of a small phase change.

[0047] The Hilbert-transformed complex signal **HB** generated by the Hilbert transformer **22** and a small phase error correction signal **CSH** which is a complex signal for correcting a phase error are input to the complex phase rotator **52**. The complex phase rotator **52** rotates a phase of the complex signal **HB** by multiplying the complex signal **HB** by a small phase error correction signal **CSH** to correct a phase error of the complex signal **HB** so that the phase error is reduced. The complex phase rotator **52** outputs the phase-error-corrected complex signal **RS2** to the phase error detector **54**. An in-phase component of the complex signal **RS2** is output to the outside of the phase error correction circuit of FIG. **3**.

[0048] The phase error detector **54** is the same as the phase error detector **24** of FIG. **1**. The low pass filter **56** is the same as the low pass filter **26** of FIG. **1**, except that a different parameter is used. Therefore, the detailed description thereof will be omitted.

[0049] The complex signal generator **58** generates, based on an output of the low pass filter **56**, the small phase error correction signal **CSH** for correcting a phase error of the complex signal **HB** and outputs the small phase error correction signal **CSH** to the complex phase rotator **52**. The small phase error correction signal **CSH** is a complex conjugate signal of a detected phase error.

[0050] As has been described, in the phase error correction circuit of FIG. **3**, a circuit causing a large delay does not exist in a loop of the small phase error corrector **50**. Accordingly, fast changes in phase noise and a small phase error can be tracked and a phase error can be corrected.

INDUSTRIAL APPLICABILITY

[0051] As has been described, according to the present invention, highly precise phase error correction can be performed and also increase in circuit size can be suppressed. Therefore, the present invention is useful as a demodulator for demodulating a VSB modulated signal.